CAE 464/517 HVAC Systems Design

Spring 2023

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Heating and cooling loads calculations

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Dr. Mohammad Heidarinejad, Ph.D., P.E.
Civil, Architectural and Environmental Engineering
Illinois Institute of Technology
muh182@iit.edu

ANNOUNCEMENTS

Announcements

- Homework 1 is graded, and the solution is posted
- Homework 2 is due tonight
- Homework 3 will be posted on Thursday
- The project will be distributed soon (working on the Revit model)
- Did you watch the recording and see the slides for the OpenStudio training?

Announcements

- Start thinking about your group for the project

Group #	Team Members
1	
2	
3	
4	
5	
6	
7	

RECAP

Recap

- Winter design conditions:
  - ❑ Use ASHRAE Design Data from the Fundamentals Handbook
  - ❑ The 99.6% and 99% indicate the risk level desired
  - ❑ When 99% is selected, it means the outdoor temperatures have been equaled or exceeded by 99% of the total number of hours in a year (8760 hours):
    - 99.6% (0.4%) ~ 35 hours
    - 99.0% (1.0%) ~ 88 hours
    - 98.0 (2.0%) ~ 175 hours
    - 95.0 (5.0%) ~ 438 hours

Recap

- Let's look at Chapter 14:

Station	Lat	Long	Elev	Heating DB 99.6%	Heating DB 99%
SW GEORGIA REGIONAL	31.536N	84.194W	190	26.6	29.6
VALDOSTA REGIONAL	30.783N	83.277W	198	27.7	30.8
Hawaii					
HILO INTL	19.719N	155.053W	38	61.6	62.8
HONOLULU INTL	21.324N	157.929W	7	62.5	64.5
KALAELOA	21.317N	158.067W	33	60.4	62.5
KANEOHE MCAS	21.450N	157.768W	24	64.0	65.9
Idaho					
BOISE AP	43.567N	116.241W	2814	9.4	15.9
CALDWELL INDUSTRIAL AP	43.650N	116.633W	2429	9.6	15.7
COEUR D'ALENE AP	47.767N	116.817W	2307	5.8	10.4
IDAHO FALLS REGIONAL	43.516N	112.067W	4729	-6.6	-0.3
LEWISTON-NEZ PERCE CO REGL	46.375N	117.016W	1436	13.0	18.8
MAGIC VALLEY REGIONAL	42.482N	114.487W	4151	7.6	12.0
POCATELLO REGIONAL	42.920N	112.571W	4452	-2.0	3.8
Illinois					
ABRAHAM LINCOLN CAPITAL	39.845N	89.684W	594	1.1	6.9
AURORA MUNICIPAL	41.770N	88.481W	710	-4.9	0.7
CHICAGO MIDWAY INTL	41.786N	87.752W	612	0.5	6.1
CHICAGO O'HARE INTL	41.995N	87.934W	662	-1.0	4.4
CHICAGO ROCKFORD INTL	42.193N	89.093W	730	-5.4	0.3

2021

Station	Lat	Long	Elev	Heating DB 99.6%	Heating DB 99%
Hawaii					
HILO INTL	19.72N	155.05W	38	61.7	62.9
HONOLULU INTL	21.32N	157.93W	7	63.5	65.1
KALAELOA	21.32N	158.07W	33	60.7	62.6
KANEOHE MCAS	21.45N	157.77W	24	63.8	65.8
Idaho					
BOISE	43.57N	116.24W	2814	11.4	16.4
CALDWELL	43.65N	116.63W	2429	9.5	15.6
COEUR D'ALENE	47.77N	116.82W	2307	6.7	11.5
IDAHO FALLS	43.52N	112.06W	4733	-5.5	0.4
LEWISTON	46.38N	117.02W	1436	13.8	19.4
MAGIC VALLEY	42.48N	114.49W	4151	7.0	11.6
POCATELLO	42.92N	112.57W	4452	-0.5	4.8
Illinois					
AURORA	41.77N	88.48W	710	-6.0	0.2
CHAMPAIGN WILLARD	40.04N	88.28W	754	-1.7	3.7
CHICAGO DUPAGE	41.91N	88.25W	754	-3.8	1.2
CHICAGO EXECUTIVE	42.12N	87.91W	636	-1.0	3.5
CHICAGO MIDWAY	41.79N	87.75W	612	0.0	5.0
CHICAGO O'HARE	41.96N	87.93W	662	-1.7	3.3
CHICAGO ROCKFORD	42.19N	89.09W	730	-6.2	-0.5

2017

Recap

- Summer design conditions
  - DB is dry-bulb temperature
  - MWB is the mean-coincident-wet-bulb temperature
  - The 0.4%, 1% and 2% mean the percentile of the total hours may not meet indoor design conditions

Recap

- Sizing HVAC systems is among one of important reasons for heating and cooling load calculations:
  - ❑ Size for the worst peak load condition (When that would be in summer and winter?)
  - ❑ Avoid running the system part-load (What does it mean?)
  - ❑ Consider realistic sizing factors (What’s the current practice?)

Recap

- **Heating Loads:**
  - ❑ Simple
  - ❑ Steady-state
  - ❑ Solar radiation is ignored
  - ❑ No effect of thermal mass or heat gain

- **Cooling Loads:**
  - ❑ Complex (require separating the convective and radiative from the loads)
  - ❑ Time-dependent (usually 24 hours)
  - ❑ Solar radiation is considered
  - ❑ Effects of internal heat gains and thermal mass are important

Recap

- Five main heat and mass processes are important for the heating and cooling load calculations:

    1. **Transmission** (e.g., walls, floor, roof, windows)
    2. **Solar Heat Gain** (e.g., walls, windows)
    3. **Infiltration** (e.g., through window frame, door openings)
    4. **Internal heat gain** (e.g., lights, people, equipment)
    5. **Ventilation** (e.g., mechanical systems)

HEATING LOAD CALCULATIONS

(Please, see Chapters 17 and 18 for additional information)

Heating Load Calculations

- For the heating load calculations:
  - ❑ Assume outdoor temperature is lower than the conditioned space temperature
  - ❑ Do not consider any credits for the impacts of solar, internal heat gains, or building thermal mass
  - ❑ Thermal bridging has impact on the heating loads than the cooling loads

Heating Load Calculations

- Imagine a commercial retail store at night nighttime:
  - ❑ Temperature setbacks are in place
  - ❑ Lights and internal gains are off
  - ❑ Heat flux is only due to conduction and infiltration

Heating Load Calculation

- Consider the following heat loads:
  - Transmission
  - Infiltration
  - Ventilation

Heating Load Calculation

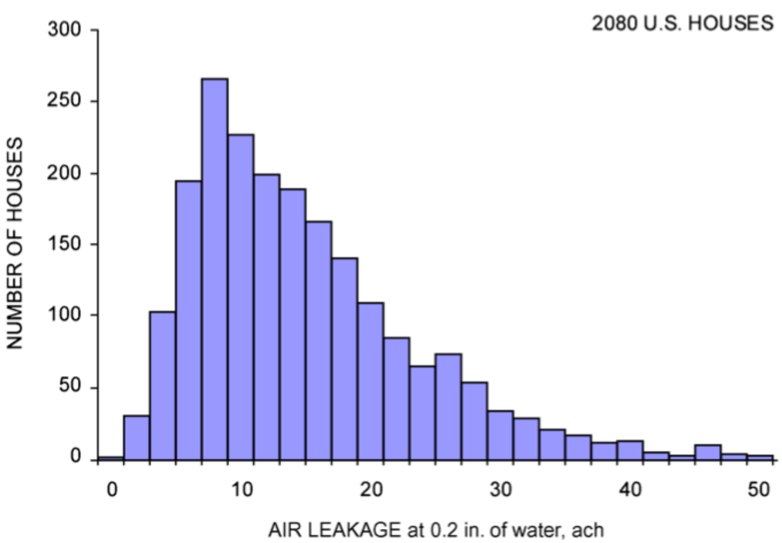
- Consider the following heat loads:
  - Transmission

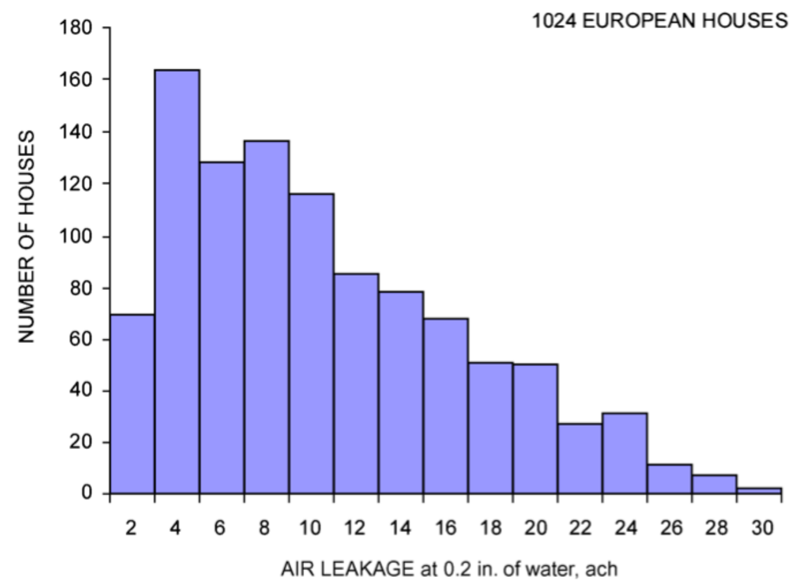
$$R_{tot} = \frac{1}{UA}$$

$$q_x = UA\Delta T_{overall}$$

Heating Load Calculation

- Consider the following heat loads:
  - ❑ Infiltration
    - An unintentional air through building envelops
    - There are databases of values for the infiltration values





(See Figure 10 – Chapter 16)

Heating Load Calculations

- The recommended steps are:
  - ❑ Select outdoor design condition criteria and numbers
  - ❑ Select indoor conditioned space temperature
  - ❑ Estimate temperature in any adjacent unheated spaces
  - ❑ Identify transmission coefficients and compute conduction heat losses to exterior
  - ❑ Consider infiltration load

Heating Load Calculations

- Consider the following heat loads for exterior surfaces above grade:

$$R_{tot} = \frac{1}{UA}$$

$$Q = UA\Delta t = A \times HF$$

HF is the heating load factor in Btu/h-ft^2

Heating Load Calculations

- How do you account for A, $\Delta T_{overall}$ and U?
  - ❑ Exterior surface above grade
  - ❑ Below grade surface
  - ❑ At grade surface
  - ❑ Surface adjacent to unconditioned spaces

- Define heating load factor:

$$HF = U\Delta T_{overall}$$

Heating Load Calculations

- The recommended steps are:
  - ❑ Select outdoor design condition criteria and numbers
  - ❑ Select indoor conditioned space temperature
  - ❑ Estimate temperature in any adjacent unheated spaces
  - ❑ Identify transmission coefficients and compute conduction heat losses to exterior
  - ❑ Calculate infiltration and other outdoor air
  - ❑ Sum the losses

Heating Load Calculations

- See Section 9 of Chapter 18 for the three examples:
  - ❑ Single room example
  - ❑ Single room example peak heating load
  - ❑ Whole building example

RSTM (RADIANT TIME SERIES METHOD)

RSTM

- Radiant Time Series Method (RTSM) is a simplified method for the calculation of cooling loads with these assumptions:
  - ❑ *Calculation Period:* Consider only a single day (ignore the stored energy)
  - ❑ *Exterior Surface Heat Balance:* Assume the sol-air temperature to account for solar irradiance and convection
  - ❑ *Interior Surface Heat Balance and Room Temperature:* Consider the delay radiative fractions

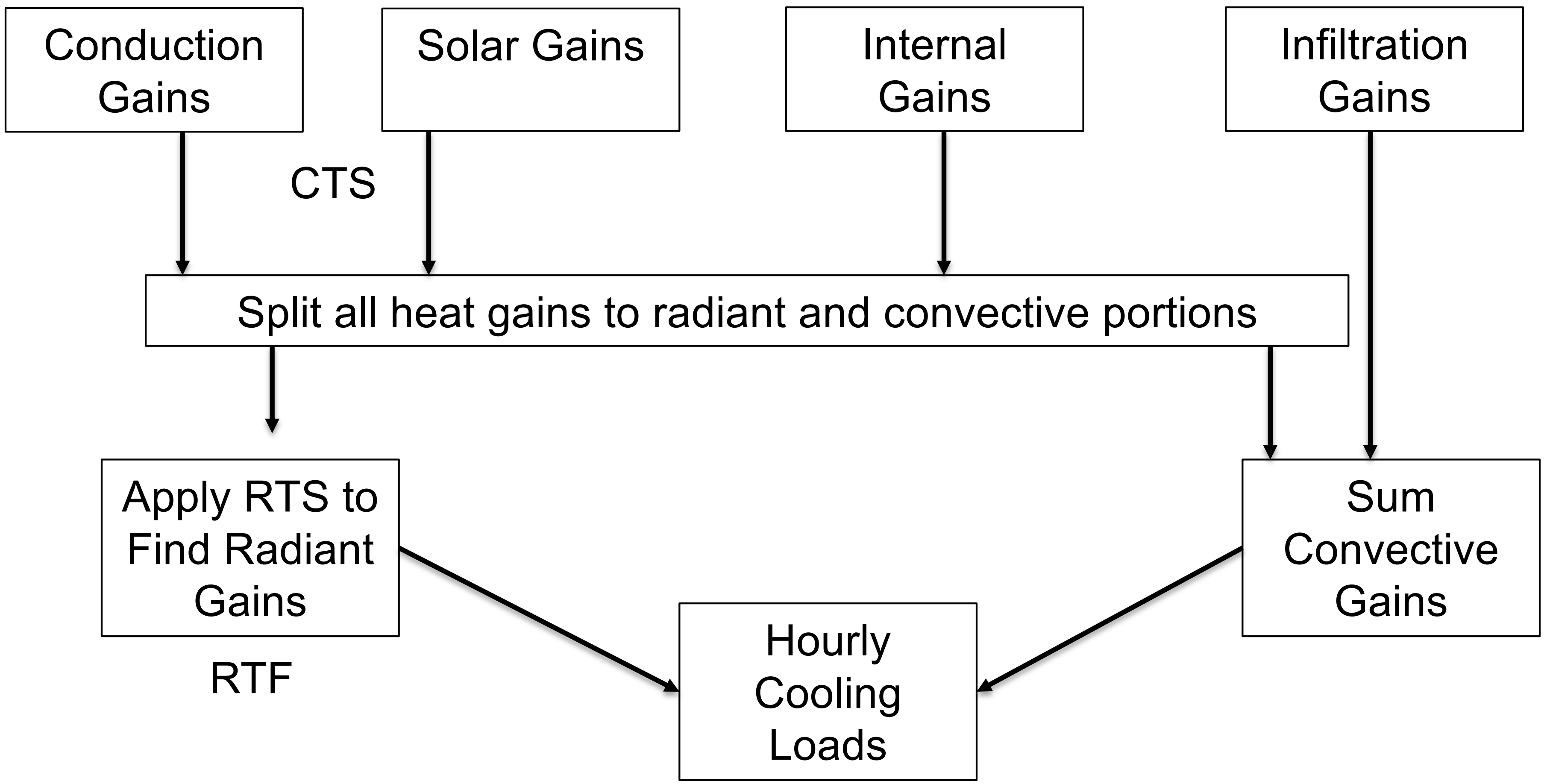
RSTM

- Separate sensible and latent components of the loads for cooling load calculations:
  - Sensible heat is directly added to the conditioned space(s) by conduction or radiation
  - Latent heat gain occurs when moisture is added
  - Designs may be influenced by sensible/latent loads or both
  - In a space with sensible-load-driven, the cooling supply air has surplus capacity to dehumidify
  - In a space with latent-load-driven, calculating the supply airflow using sensible load does not meet the dehumidification needed (needs subcooling, reheat, or other means)

COOLING LOAD CALCULATIONS

Cooling Load Calculation

- Radiant Transfer Series Method (RTSM)



CTS = Conduction Transfer Series
RTF = Radiant Transfer Function

Cooling Load Calculation

- Space heat gain is the instantaneous rate of heat transfer in the space

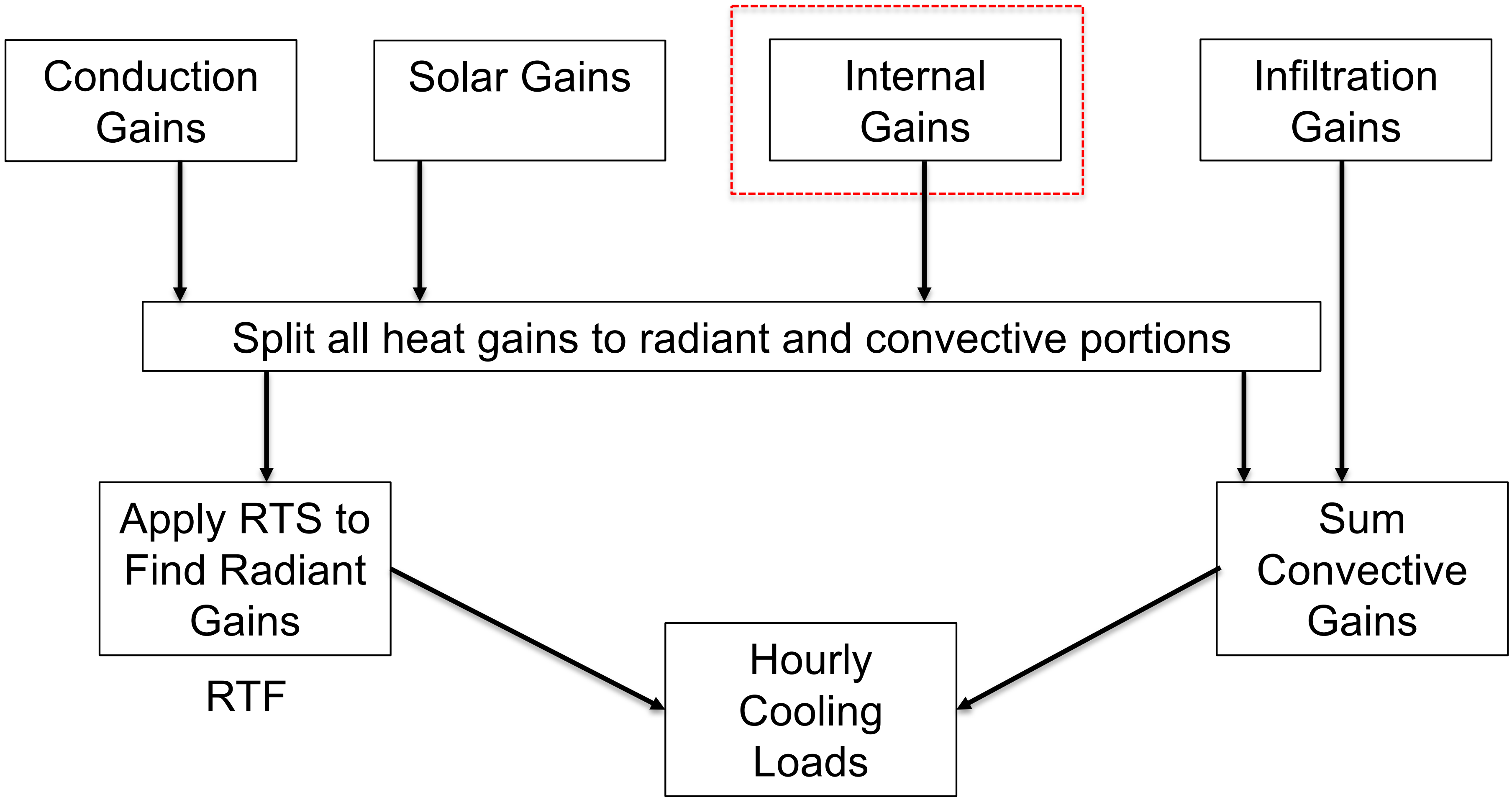
- Main components to consider are:

  1. **Internal** (e.g., Interior lights, appliance and equipment)
  2. **External** (e.g., walls, roof)
  3. **Infiltration**
  4. **Systems** (e.g., ventilation, fan heat)

COOLING LOAD CALCULATIONS DUE TO LIGHTING

Internal Loads (Lighting)

- Radiant Transfer Series Method (RTSM)



CTS = Conduction Transfer Series
RTF = Radiant Transfer Function

Internal Loads (Lighting)

- The portion of the heat emitting from lights which are in the form of radiant energy is not an instantaneous load:
  - Does not immediately affect the load on air-conditioning systems
  - The radiant energy is first absorbed by surfaces and increase their temperatures
  - Once the temperature of these objects rises above the air temperature, heat is released from the surfaces and becomes a cooling load (Similar to the long-wave radiation)

Internal Loads (Lighting)

- Method 1: Cooling load due to instantaneous sensible heat gain from electric lighting are calculated as:

$$q_{el} = 3.41\, W \times F_{ul} \times F_{sa}$$

- ❑ q_{el}: Heat gain [Btu/h]
- ❑ W: Total light wattage [W]
- ❑ F_{ul}: Lighting use factor
- ❑ F_{sa}: Lighting special allowance factor
- ❑ 3.41: Conversation factor

Internal Loads (Lighting)

- Method 2: Lighting power density

Table 2 Lighting Power Densities Using Space-by-Space Method

Common Space Types[a]	LPD, W/ft²	Common Space Types[a]	LPD, W/ft²	Building-Specific Space Types*	LPD, W/f
Atrium		**Loading Dock, Interior**	0.47	Playing area	1.20
≤40 ft high	0.03/ft total height	**Lobby**		**Health Care Facility**	
		In facility for the visually impaired (and not used primarily by staff)[c]	1.80	Exam/treatment room	1.66
>40 ft high	0.40 + 0.02/ft total height			Imaging room	1.51
		For elevator	0.64	Medical supply room	0.74
Audience Seating Area		In hotel	1.06	Nursery	0.88
In auditorium	0.63	In motion picture theater	0.59	Nurses' station	0.71
In convention center	0.82	In performing arts theater	2.00	Operating room	2.48
In gymnasium	0.65	All other lobbies	0.90	Patient room	0.62
In motion picture theater	1.14	**Locker Room**	0.75	Physical therapy room	0.91
In penitentiary	0.28	**Lounge/Breakroom**		Recovery room	1.15
In performing arts theater	2.43	In health care facility	0.92	**Library**	
In religious building	1.53	All other lounges/breakrooms	0.73	Reading area	1.06
In sports arena	0.43	Enclosed and ≤250 ft²	1.11	Stacks	1.71
All other audience seating areas	0.43	Enclosed and >250 ft²	1.11	**Manufacturing Facility**	
Banking Activity Area	1.01	Open plan	0.98	Detailed manufacturing area	1.29
Breakroom (*See* Lounge/Breakroom)		**Office**		Equipment room	0.74
Classroom/Lecture Hall/Training Room		Enclosed	1.11	Extra-high-bay area (>50 ft floor-	1.05

(Please, see Chapters 178 - Table 2)

Internal Loads (Lighting)

Table 9.5.1 *Lighting Power Density* Allowances Using the *Building* Area Method

Building Area Type[a]	*LPD*, W/ft^2
Automotive facility	0.75
Convention center	0.64
Courthouse	0.79
Dining: Bar lounge/leisure	0.80
Dining: Cafeteria/fast food	0.76
Dining: Family	0.71
Dormitory	0.53
Exercise center	0.72
Fire station	0.56
Gymnasium	0.76
Health-care clinic	0.81
Hospital	0.96
Hotel/motel	0.56
Library	0.83
Manufacturing facility	0.82
Motion picture theater	0.44
Multifamily	0.45
Museum	0.55
Office	0.64
Parking garage	0.18

(ASHRAE 90.1 2019)

Internal Loads (Lighting)

Table 2 Lighting Power Densities Using Space-by-Space Method

Common Space Types[a]	LPD, W/ft²
Atrium	
≤40 ft high	0.03/ft total height
>40 ft high	0.40 + 0.02/ft total height
Audience Seating Area	
In auditorium	0.63
In convention center	0.82
In gymnasium	0.65
In motion picture theater	1.14
In penitentiary	0.28
In performing arts theater	2.43
In religious building	1.53
In sports arena	0.43
All other audience seating areas	0.43
Banking Activity Area	1.01
Breakroom (*See* Lounge/Breakroom)	
Classroom/Lecture Hall/Training Room	
In penitentiary	1.34
All other classrooms/lecture halls/ training rooms	1.24
Conference/Meeting/Multipurpose Room	1.23
Confinement Cells	0.81
Copy/Print Room	0.72
Corridor[b]	
In facility for visually impaired (and not used primarily by staff)[c]	0.92
In hospital	0.99
In manufacturing facility	0.41
All other corridors	0.66
Courtroom	1.72
Computer Room	1.71
Dining Area	
In penitentiary	0.96
In facility for visually impaired (and not used primarily by staff)[c]	2.65
In bar/lounge or leisure dining	1.07
In cafeteria or fast food dining	0.65
In family dining	0.89
All other dining areas	0.65
Electrical/Mechanical Room[f]	0.42
Emergency Vehicle Garage	0.56
Food Preparation Area	1.21
Guest Room	0.91
Laboratory	
In or as classroom	1.43
All other laboratories	1.81
Laundry/Washing Area	0.60
Loading Dock, Interior	0.47
Lobby	
In facility for the visually impaired (and not used primarily by staff)[c]	1.80
For elevator	0.64
In hotel	1.06
In motion picture theater	0.59
In performing arts theater	2.00
All other lobbies	0.90
Locker Room	0.75
Lounge/Breakroom	
In health care facility	0.92
All other lounges/breakrooms	0.73
Enclosed and ≤250 ft²	1.11
Enclosed and >250 ft²	1.11
Open plan	0.98
Office	
Enclosed	1.11
Open plan	0.98
Parking Area, Interior	0.19
Pharmacy Area	1.68
Restroom	
In facility for the visually impaired (and not used primarily by staff)[c]	1.21
All other restrooms	0.98
Sales Area[d]	1.44
Seating Area, General	0.54
Stairway	
Space containing stairway determines LPD and control requirements for stairway.	
Stairwell	0.69
Storage Room	
<50 ft²	1.24
All other storage rooms	0.63
Vehicular Maintenance Area	0.67
Building-Specific Space Types*	**LPD, W/ft²**
Facility for Visually Impaired[c]	
Chapel (used primarily by residents)	2.21
Recreation room/common living room (and not used primarily by staff)	2.41
Automotive (*See* Vehicular Maintenance Area)	
Convention Center, Exhibit Space	1.45
Dormitory/Living Quarters	0.38
Fire Station, Sleeping Quarters	0.22
Gymnasium/Fitness Center	
Exercise area	0.72
Playing area	1.20
Health Care Facility	
Exam/treatment room	1.66
Imaging room	1.51
Medical supply room	0.74
Nursery	0.88
Nurses' station	0.71
Operating room	2.48
Patient room	0.62
Physical therapy room	0.91
Recovery room	1.15
Library	
Reading area	1.06
Stacks	1.71
Manufacturing Facility	
Detailed manufacturing area	1.29
Equipment room	0.74
Extra-high-bay area (>50 ft floor-to-ceiling height)	1.05
High-bay area (25 to 50 ft floor-to-ceiling height)	1.23
Low bay area (<25 ft floor-to-ceiling height)	1.19
Museum	
General exhibition area	1.05
Restoration room	1.02
Performing Arts Theater, Dressing Room	0.61
Post Office, Sorting Area	0.94
Religious Buildings	
Fellowship hall	0.64
Worship/pulpit/choir area	1.53
Retail Facilities	
Dressing/fitting room	0.71
Mall concourse	1.10
Sports Arena, Playing Area	
For Class I facility	3.68
For Class II facility	2.40
For Class III facility	1.80
For Class IV facility	1.20
Transportation Facility	
In baggage/carousel area	0.53
In airport concourse	0.36
At terminal ticket counter	0.80
Warehouse—Storage Area	
For medium to bulky, palletized items	0.58
For smaller, hand-carried items[e]	0.95

Source: ASHRAE *Standard* 90.1-2013.

[a]In cases where both a common space type and a building-specific type are listed, the building-specific space type applies.

[b]In corridors, extra lighting power density allowance is granted when corridor width is <8 ft and is not based on room/corridor ratio (RCR).

[c]A facility for the visually impaired one that can be documented as being designed to comply with light levels in ANSI/IES RP-28 and is (or will be) licensed by local/state authorities for either senior long-term care, adult daycare, senior support, and/or people with special visual needs.

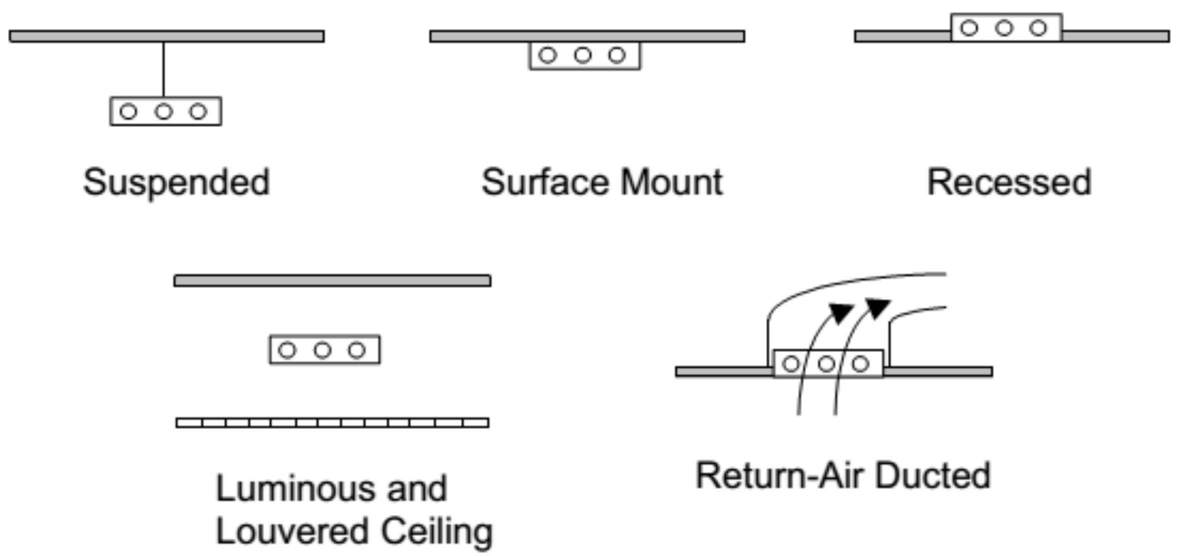
[d]For accent lighting, see section 9.6.2(b) of ASHRAE *Standard* 90.1-2013.

[e]Sometimes called a picking area.

[f]An additional 0.53 W/ft² is allowed *only* if this additional lighting is controlled separately from the base allowance of 0.42 W/ft².

Internal Loads (Lighting)

$f_{convected}$ = 1.0 – (Return Air Fraction + Fraction Radiant + Fraction Visible)



Field Name	Luminaire Configuration, Fluorescent Lighting				
	Suspended	Surface mount	Recessed	Luminous and louvered ceiling	Return-air ducted
Return Air Fraction	0.0	0.0	0.0	0.0	0.54
Fraction Radiant	0.42	0.72	0.37	0.37	0.18
Fraction Visible	0.18	0.18	0.18	0.18	0.18
$f_{convected}$	*0.40*	*0.10*	*0.45*	*0.45*	*0.10*

EnergyPlus. Input/Output Reference

Internal Loads (Lighting)

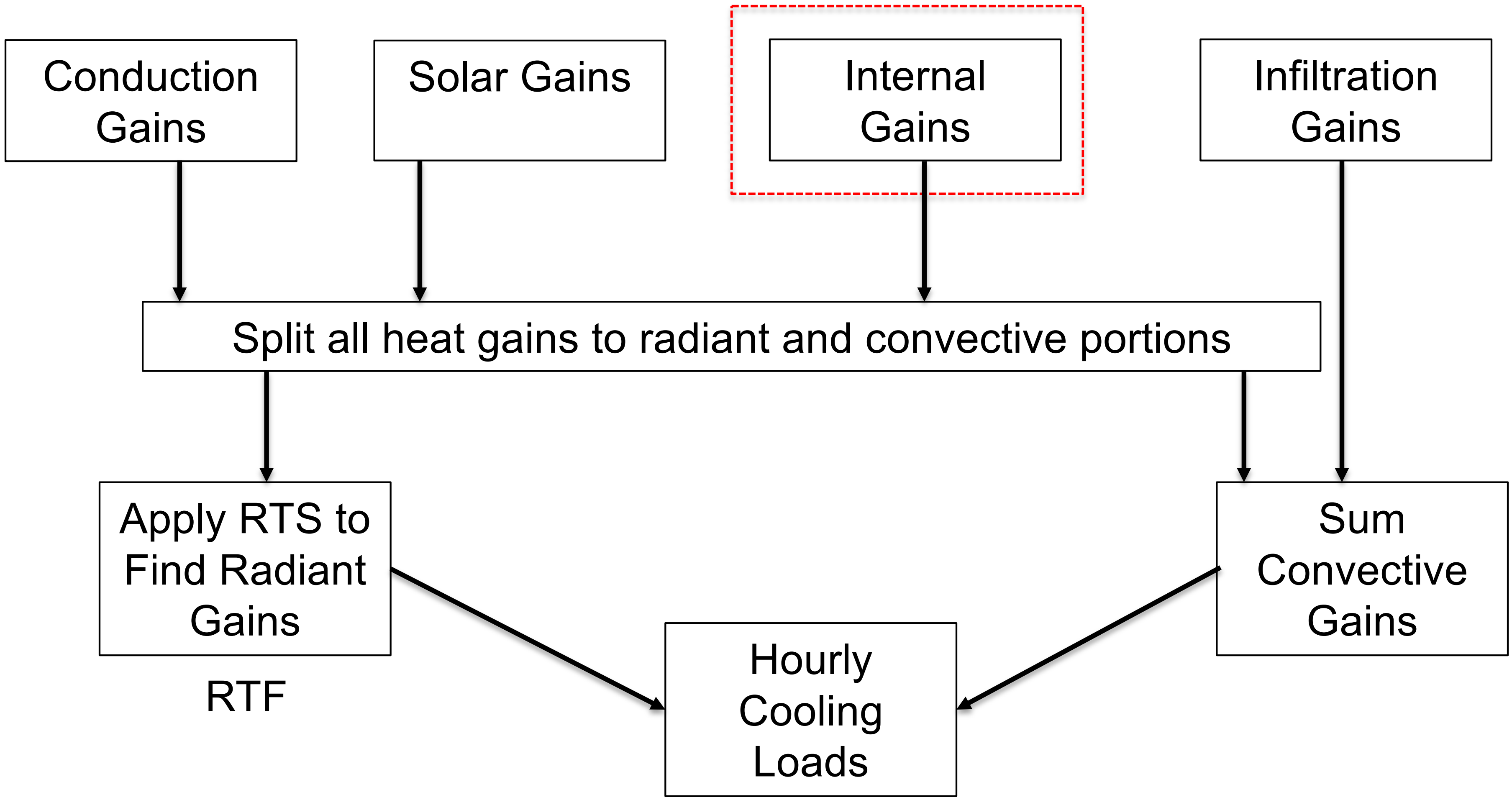
Table 3 Lighting Heat Gain Parameters for Typical Operating Conditions

Luminaire Category	Space Fraction	Radiative Fraction	Notes
Recessed fluorescent luminaire without lens	0.64 to 0.74	0.48 to 0.68	• Use middle values in most situations • May use higher space fraction, and lower radiative fraction for luminaire with side-slot returns • May use lower values of both fractions for direct/indirect luminaire • May use higher values of both fractions for ducted returns
Recessed fluorescent luminaire with lens	0.40 to 0.50	0.61 to 0.73	• May adjust values in the same way as for recessed fluorescent luminaire without lens
Downlight compact fluorescent luminaire	0.12 to 0.24	0.95 to 1.0	• Use middle or high values if detailed features are unknown • Use low value for space fraction and high value for radiative fraction if there are large holes in luminaire's reflector
Downlight incandescent luminaire	0.70 to 0.80	0.95 to 1.0	• Use middle values if lamp type is unknown • Use low value for space fraction if standard lamp (i.e. A-lamp) is used • Use high value for space fraction if reflector lamp (i.e. BR-lamp) is used
Non-in-ceiling fluorescent luminaire	1.0	0.5 to 0.57	• Use lower value for radiative fraction for surface-mounted luminaire • Use higher value for radiative fraction for pendant luminaire

COOLING LOAD CALCULATIONS DUE TO PEOPLE

Internal Loads (People)

- Radiant Transfer Series Method (RTSM)



CTS = Conduction Transfer Series
RTF = Radiant Transfer Function

Internal Loads (People)

Table 1 Representative Rates at Which Heat and Moisture Are Given Off by Human Beings in Different States of Activity

		Total Heat, Btu/h		Sensible	Latent	% Sensible Heat that is Radiant[b]	
Degree of Activity	**Location**	**Adult Male**	**Adjusted, M/F[a]**	**Heat, Btu/h**	**Heat, Btu/h**	**Low V**	**High V**
Seated at theater	Theater	390	350	245	105	60	27
Seated, very light work	Offices, hotels, apartments	450	400	245	155		
Moderately active office work	Offices, hotels, apartments	475	450	250	200		
Standing, light work; walking	Department store; retail store	550	450	250	200	58	38
Walking, standing	Drug store, bank	550	500	250	250		
Sedentary work	Restaurant[c]	490	550	275	275		
Light bench work	Factory	800	750	275	475		
Moderate dancing	Dance hall	900	850	305	545	49	35
Walking 3 mph; light machine work	Factory	1000	1000	375	625		
Bowling[d]	Bowling alley	1500	1450	580	870		
Heavy work	Factory	1500	1450	580	870	54	19
Heavy machine work; lifting	Factory	1600	1600	635	965		
Athletics	Gymnasium	2000	1800	710	1090		

Notes:

1. Tabulated values are based on 75°F room dry-bulb temperature. For 80°F room dry bulb, total heat remains the same, but sensible heat values should be decreased by approximately 20%, and latent heat values increased accordingly.
2. Also see Table 4, Chapter 9, for additional rates of metabolic heat generation.
3. All values are rounded to nearest 5 Btu/h.

[a] Adjusted heat gain is based on normal percentage of men, women, and children for the application listed, and assumes that gain from an adult female is 85% of that for an adult male, and gain from a child is 75% of that for an adult male.

[b] Values approximated from data in Table 6, Chapter 9, where V is air velocity with limits shown in that table.

[c] Adjusted heat gain includes 60 Btu/h for food per individual (30 Btu/h sensible and 30 Btu/h latent).

[d] Figure one person per alley actually bowling, and all others as sitting (400 Btu/h) or standing or walking slowly (550 Btu/h).

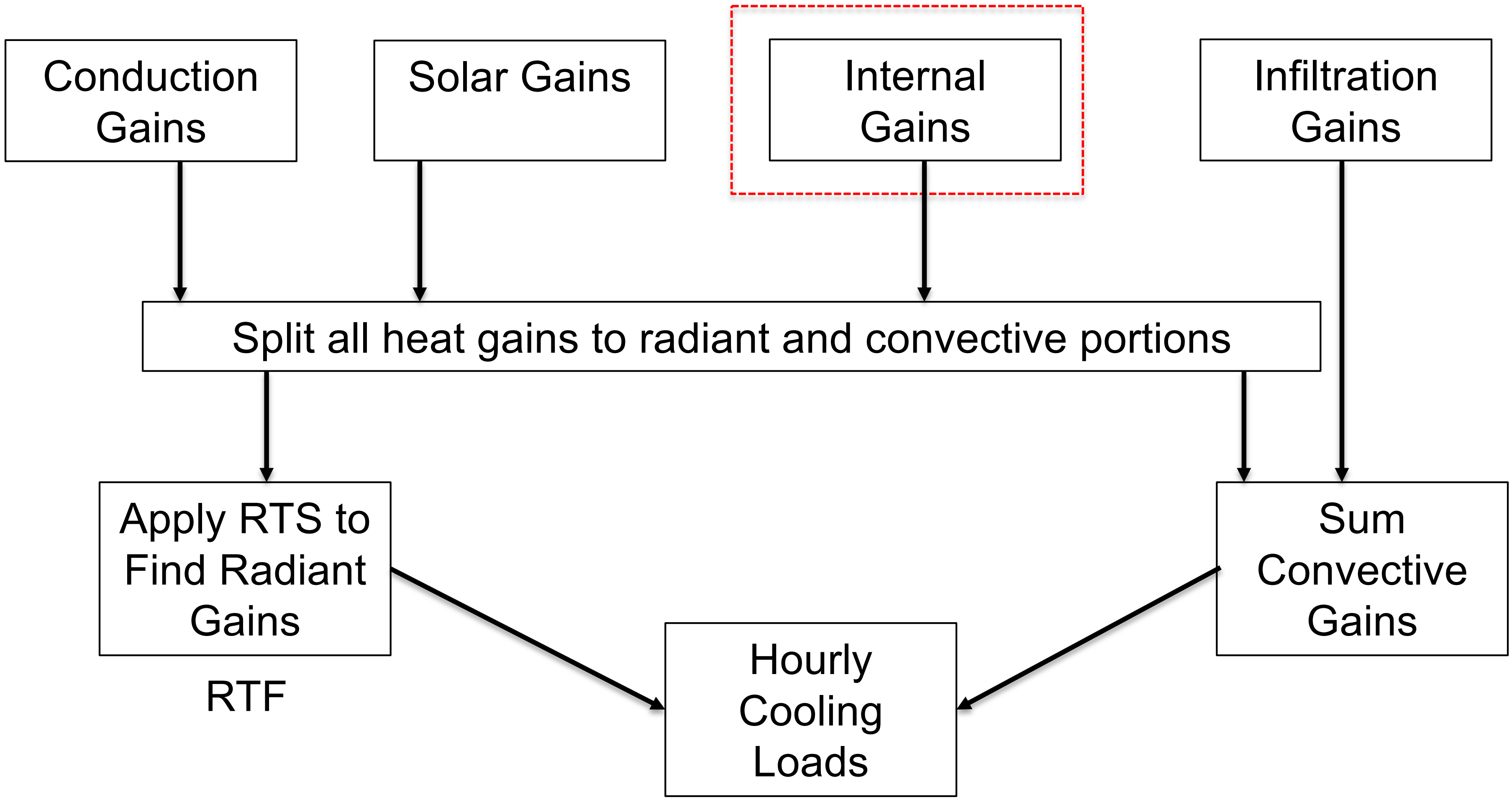
(Please, see Chapters 18 – Table 1 or Chapter 9)

Can we calculate the fraction of radiative to convective?

COOLING LOAD CALCULATIONS DUE TO APPLIANCE

Internal Loads (Appliance)

- Radiant Transfer Series Method (RTSM)



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RTF = Radiant Transfer Function

Internal Loads (Appliance)

Table 8B Recommended Heat Gain for Typical Laptops and Laptop Docking Station

Equipment	Description	Nameplate Power,[a] W	Peak Heat Gain,[b, c] W
Laptop computer	Manufacturer 1, 2.6 GHz processor, 8 GB RAM, n = 1	NA	46
	Manufacturer 2, 2.4 GHz processor, 4 GB RAM, n = 1	NA	59
Average 15-min peak power consumption (range)		53 (46-59)	
Laptop with docking station	Manufacturer 1, 2.7 GHz processor, 8 GB RAM, n = 1	NA	38
	1.6 GHz processor, 8 GB RAM, n = 2	NA	45
	2.0 GHz processor, 8 GB RAM, n = 1	NA	50
	2.6 GHz processor, 4 GB RAM, n = 1	NA	51
	2.4 GHz processor, 8 GB RAM, n = 1	NA	40
	2.6 GHz processor, 8 GB RAM, n = 1	NA	35
	2.7 GHz processor, 8 GB RAM, n = 1	NA	59
	3.0 GHz processor, 8 GB RAM, n = 3	NA	70
	2.9 GHz processor, 32 GB RAM, n = 3	NA	58
	3.0 GHz processor, 32 GB RAM, n = 1	NA	128
	3.7 GHz processor, 32 GB RAM, n = 1	NA	63
	3.1 GHz processor, 32 GB RAM, n = 1	NA	89
Average 15-min peak power consumption (range)		61 (26-151)	

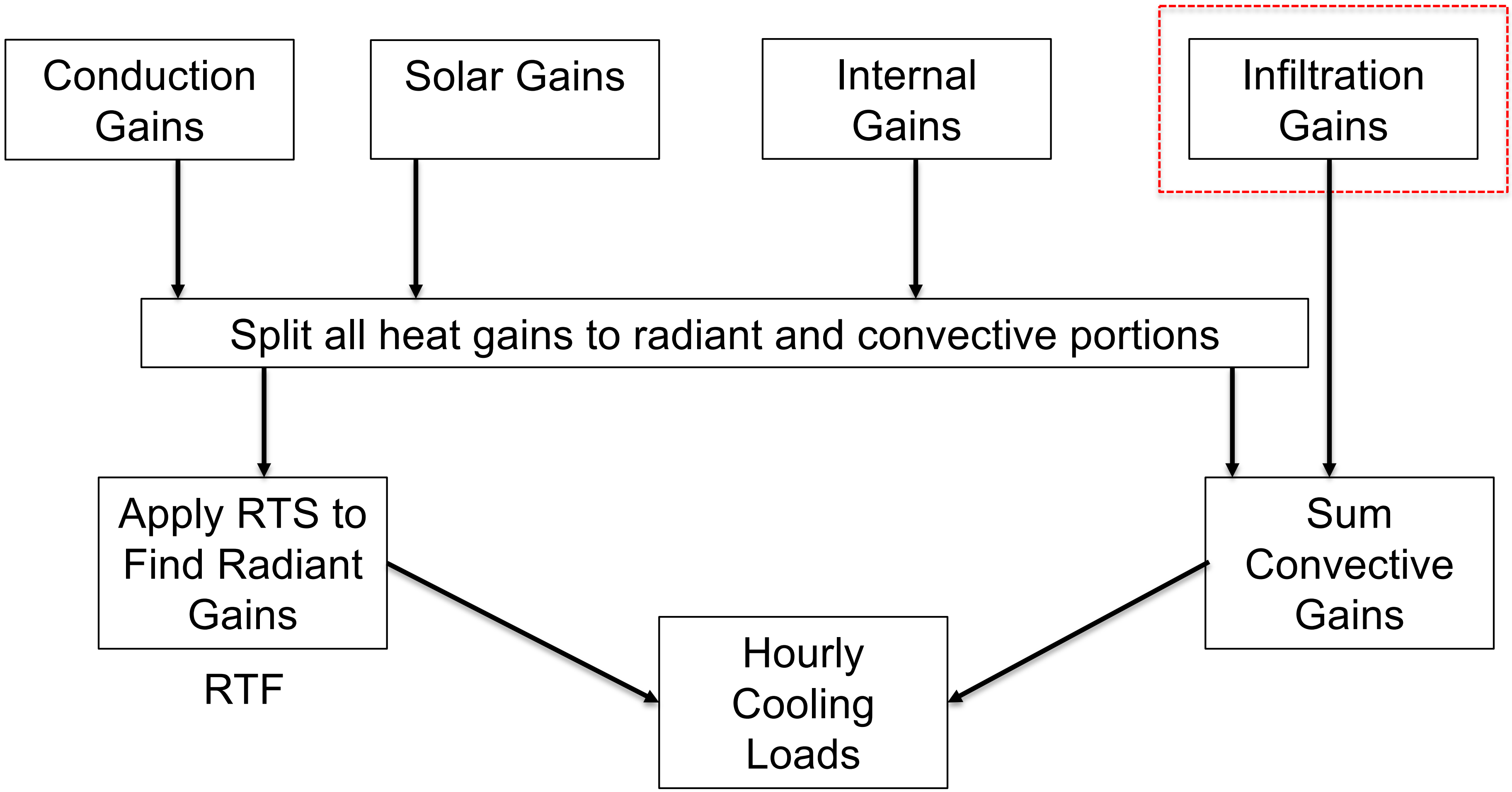
Source: Bach and Sarfraz (2017)
n = number of tested equipment of same configuration.
[a]Voltage and amperage information for laptop computer and laptop docking station is available on power supply nameplates; however, nameplate does not provide information on power consumption, where NA = not available.
[b]For equipment peak heat gain value, the highest 15-min interval of recorded data is listed in tables.
[c]Approximately 75% convective heat gain and 25% radiative heat gain.

(Please, see Chapters 17 – Table 1 or Chapter 9)

COOLING LOAD CALCULATIONS DUE TO INFILTRATION

Infiltration and Outdoor Air Load

- Radiant Transfer Series Method (RTSM)



CTS = Conduction Transfer Series
RTF = Radiant Transfer Function

Infiltration and Outdoor Air Load

- Common practice to use Air Changes Rate per Hour (ACH)
- One common practice is to estimate ACH for winter heating conditions and use the half value for summer

(Please, see Chapters 16 and Chapter 17)

Infiltration and Outdoor Air Load

- Total heat is equal to:

$$q_t = \dot{m}\Delta h$$

$$(60\frac{min}{h})(0.075\frac{lb_{da}}{ft^3})\times Q_s\times\Delta h = 4.5Q_s\times\Delta h$$

$$q_t = C_t\times Q_s\times\Delta h$$

- ❑ C_t: Total air heat factor in Btu/hr-cfm per Btu/lb (See Table 8)
- ❑ Q_s: The airflow rate

Infiltration and Outdoor Air Load

- Sensible heat is equal to:

$$q_s = \left(60\,\frac{min}{h}\right)\left(0.075\,\frac{lb_{da}}{ft^3}\right)\times(0.24 + 0.45W)\times Q_s\times\Delta t$$

❑ 0.24: Specific heat of dry air [Btu/lb-F]
❑ W: Humidity ratio [lb_w/lb_{da}]
❑ 0.45: Specific heat of water vapor [Btu/lb-F]

$$q_s = 1.1\times Q_s\times\Delta t = C_s\times Q_s\times\Delta t$$

❑ C_s: The air sensible heat factor (1.1 Btu/hr-cfm-F)

Infiltration and Outdoor Air Load

- Latent heat is equal to:

$$q_l = \left(60\,\frac{min}{h}\right)\left(0.075\,\frac{lb_{da}}{ft^3}\right)\times\left(1076\,\frac{Btu}{hr}\right)\times Q_s\times\Delta\mathrm{W}$$

❑ 1076 Btu/lb is the approximate heat content of 50% RH vapor at 75 F less than heat content of water at 50 F

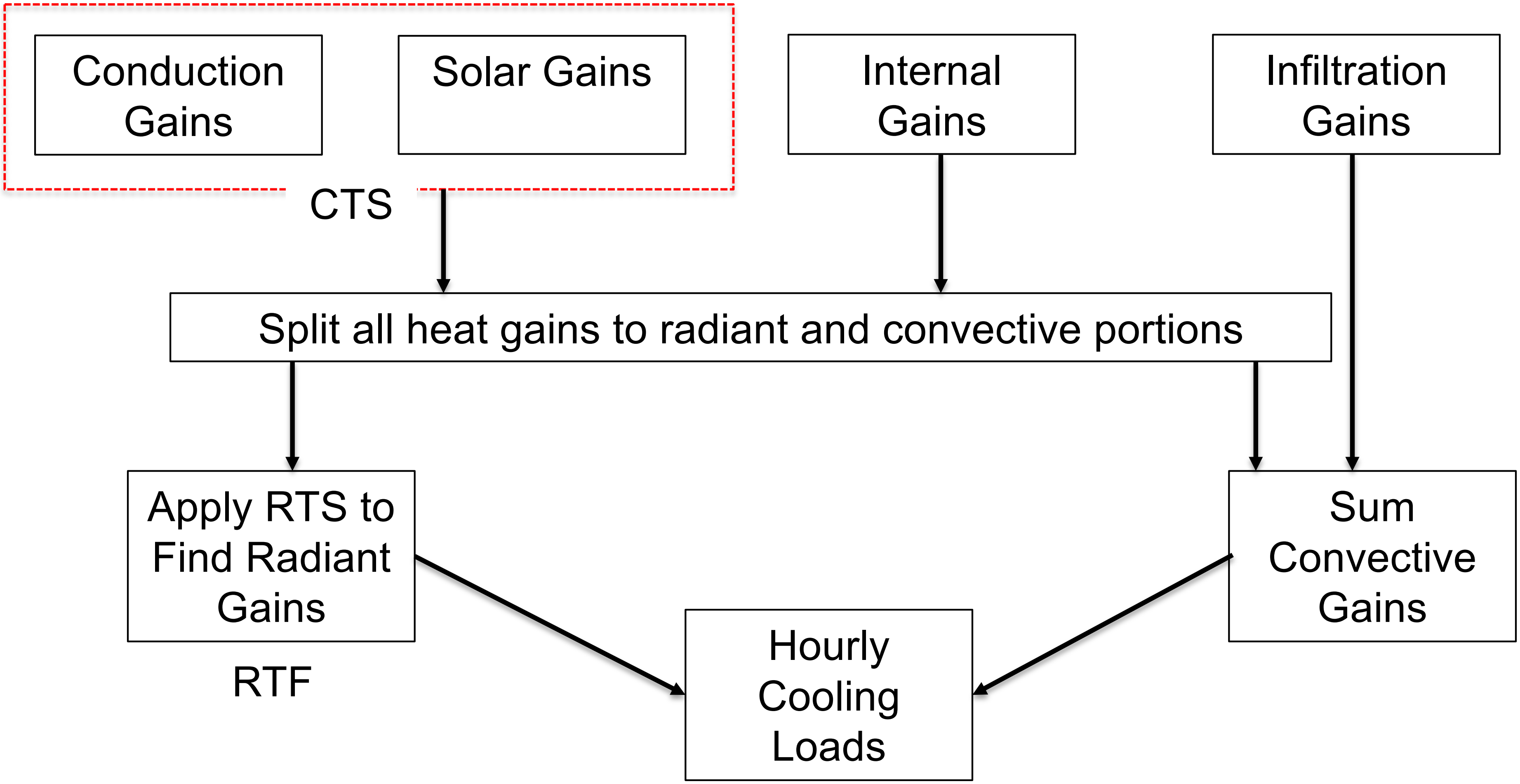
$$q_l = 4840\times Q_s\times\Delta W = C_l\times Q_s\times\Delta\mathrm{W}$$

❑ C_{l}: The air latent heat factor (4840 Btu/hr-cfm)

COOLING LOAD CALCULATIONS DUE TO ENCLOSURE

CTS

- Radiant Transfer Series Method (RTSM)



CTS = Conduction Transfer Series
RTF = Radiant Transfer Function

CTS

$$q_\theta = \sum_{j=0}^{23} c_j UA(t_{sol-air,\theta-j\delta} - t_{rc})$$

- q_θ: Hourly conductive heat gain Btu/h
- U: Overall heat transfer coefficient for the surface $\frac{Btu}{h.ft^2.F}$
- A: Surface area ft^2
- c_j: j-th conduction time series factor
- $t_{\text{sol-air},\theta-j\delta}$: Sol-air temperature °F
- t_{rc}: Presumed constant room temperature
- θ : The current hour
- δ: The time step (one hour)

CTS

- For example, at 1 pm (13), we write:

$$q_\theta = \sum_{j=0}^{23} c_j UA(t_{e,\theta-j\delta} - t_{rc})$$

$$q_{13} = \sum_{j=0}^{23} c_j UA(t_{e,13-j\delta} - t_{rc}) = [UA]\times \sum_{j=0}^{23} c_j \times(t_{e,13-j\delta} - t_{rc})$$

$$= [UA]\times[c_0\left(t_{sol-air,13} - t_{rc}\right) + c_1\left(t_{sol-air,12} - t_{rc}\right) + c_2\left(t_{sol-air,11} - t_{rc}\right) + \cdots$$

$$\ldots + c_{23}\left(t_{sol-air,14} - t_{rc}\right)]$$

CTS

- Define the sol-air temperature as a proxy for the outdoor surface temperature:

$$\frac{q}{A} = \alpha E_t + h_o(t_o - t_s) - \epsilon \Delta R$$

$$t_{sol-air} = t_o + \frac{\alpha E_t}{h_o} - \frac{\epsilon \Delta R}{h_0}$$

  - For horizontal surfaces:
    - ❑ ΔR = 20 $\frac{Btu}{h.ft^2}$
    - ❑ If ε = 1 and h_o= 3.0 $\frac{Btu}{h.ft^2F}$ the long-wave correction term is about 7°F

CTS

- CTSFs for the very light wall are:
  - ❑ Very large for the first few hours
  - ❑ Nearly zero for the remaining hours
  - ❑ Little stored energy capacity

- Heavier walls have:
  - ❑ Smaller values for the first few hours
  - ❑ Remain non-zero for many hours
  - ❑ Long delay for heavy walls

CTS

- Comparison between different wall assemblies:

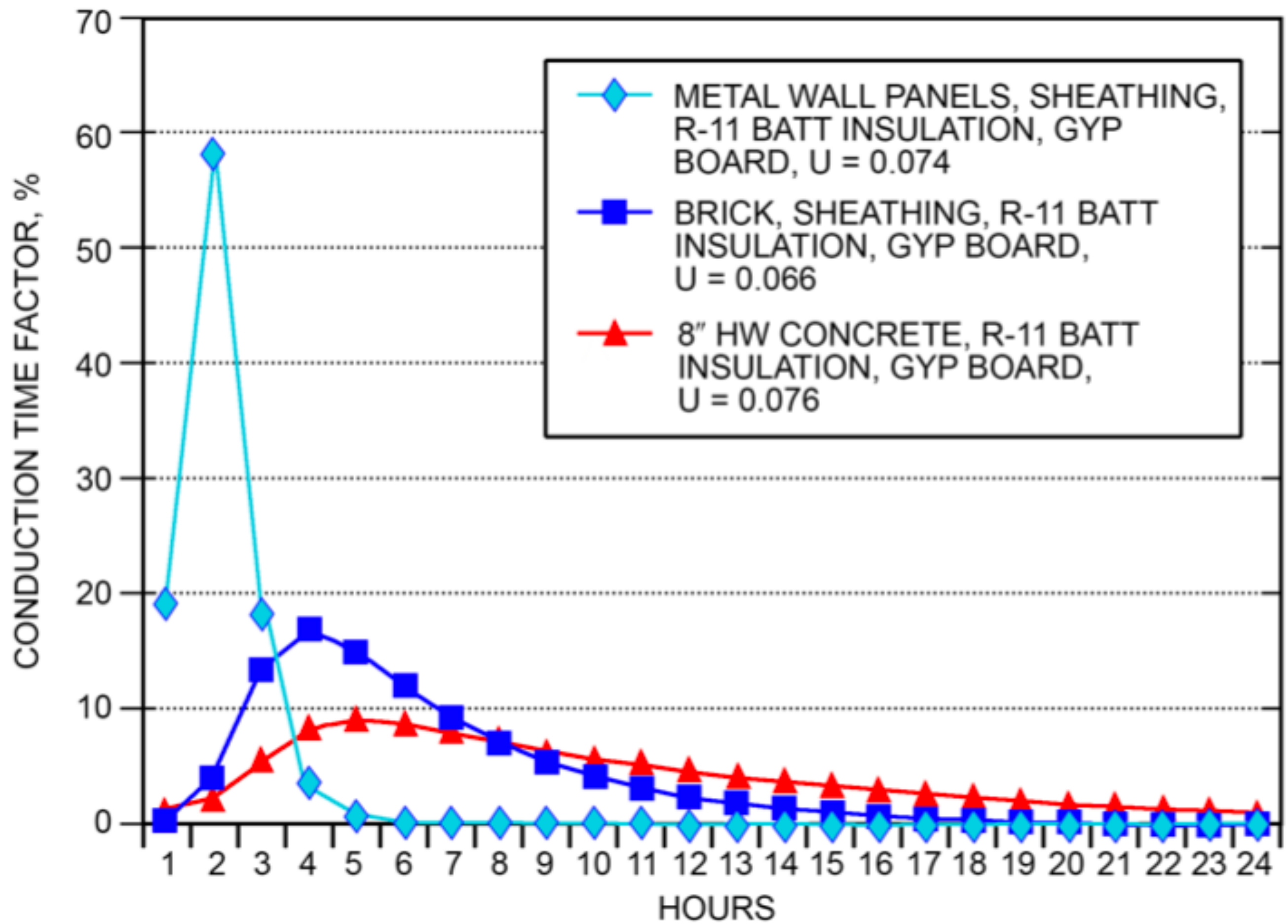


Fig. 9 CTS for Light to Heavy Walls

CTS

- Insulation has limited impacts on CTSs

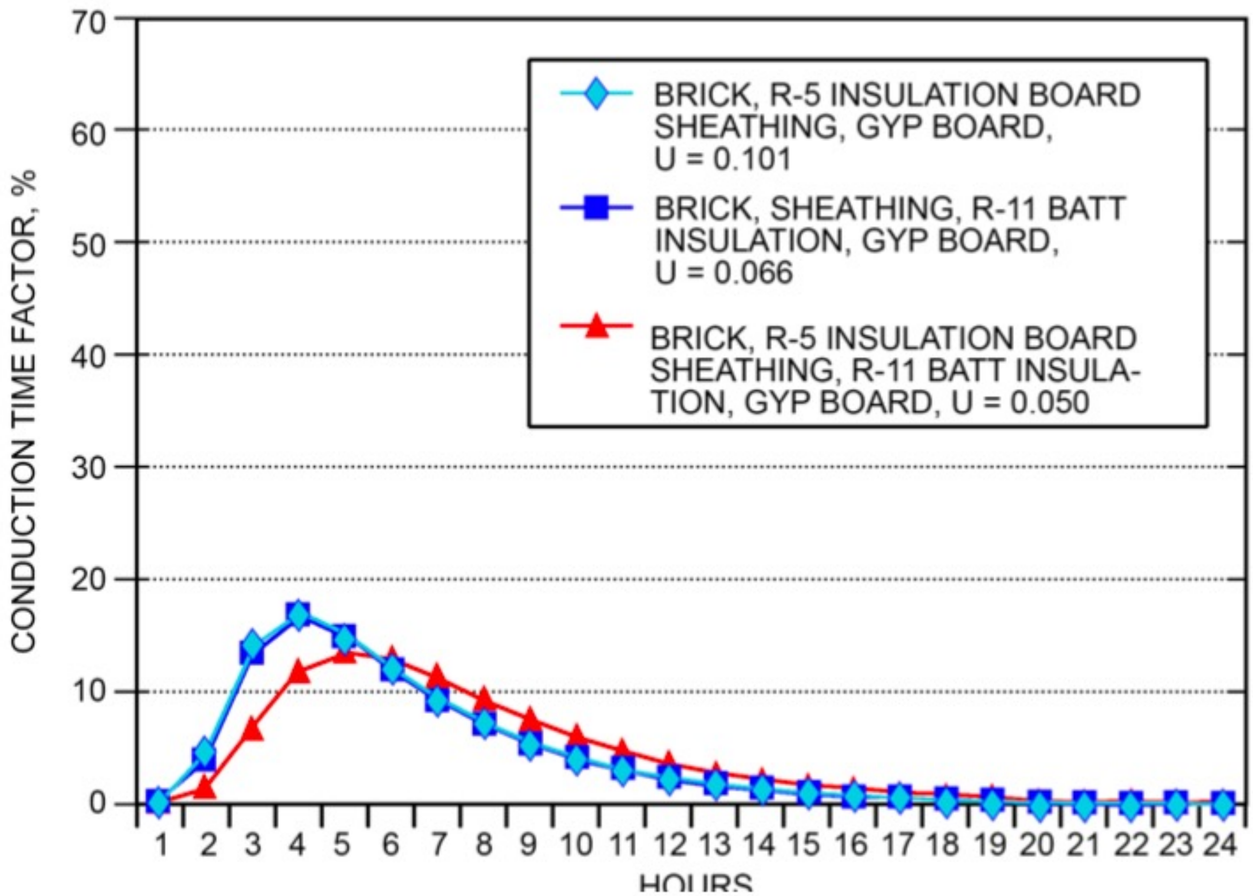


Fig. 10 CTS for Walls with Similar Mass and Increasing Insulation

CTS

Table 16 Wall Conduction Time Series (CTS) (*Continued*)

	Brick Walls								
	Brick, R-5 Insulation Board, Sheathing, Gyp. Board	Brick, R-10 Insulation Board, Sheathing, Gyp. Board	Brick, Sheathing, R-11 Batt Insulation, Gyp. Board	Brick, Sheathing, R-22 Batt Insulation, Gyp. Board	Brick, R-5 Insulation Board, Sheathing, R-11 Batt Insulation, Gyp. Board	Brick, R-5 Insulation Board, Sheathing, R-22 Batt Insulation, Gyp. Board	Brick, R-5 Insulation Board, 8 in. LW CMU	Brick, R-10 Insulation Board, 8 in. LW CMU	Brick, 8 in. LW CMU, R-11 Batt Insulation, Gyp. Board
Wall Number	21	22	23	24	25	26	27	28	29
***U*, Btu/h·ft²·°F**	0.101	0.067	0.066	0.038	0.050	0.028	0.103	0.068	0.061
Total *R*	9.9	14.9	15.1	26.1	20.1	36.1	9.7	14.7	16.4
Hour	**Conduction Time Factors, %**								
0	0.2	0.1	0.2	0.1	0.1	0.4	0.6	0.8	1.6
1	4.8	3.0	4.1	1.6	1.5	0.5	0.8	0.8	1.5
2	13.9	11.1	13.3	8.5	6.8	2.0	2.6	2.1	1.9
3	16.7	15.5	16.6	14.5	11.7	5.3	5.5	4.5	3.3
4	14.9	15.0	14.8	15.2	13.3	8.2	7.6	6.6	5.0
5	12.0	12.7	11.8	13.1	12.7	9.7	8.7	7.9	6.2
6	9.2	10.1	9.2	10.6	11.1	10.1	9.0	8.4	6.9
7	7.0	7.8	7.1	8.3	9.2	9.6	8.7	8.4	7.1
8	5.3	6.0	5.4	6.5	7.5	8.8	8.2	8.0	7.0
9	4.0	4.6	4.2	5.0	5.9	7.8	7.4	7.4	6.7
10	3.0	3.5	3.2	3.9	4.7	6.8	6.6	6.7	6.3
11	2.3	2.6	2.4	3.0	3.6	5.8	5.8	6.0	5.9
12	1.7	2.0	1.9	2.3	2.8	4.9	5.0	5.3	5.4
13	1.3	1.5	1.4	1.8	2.2	4.1	4.3	4.7	5.0
14	1.0	1.1	1.1	1.4	1.7	3.4	3.7	4.1	4.5
15	0.7	0.9	0.8	1.1	1.3	2.8	3.1	3.5	4.1
16	0.5	0.7	0.6	0.8	1.0	2.3	2.6	3.0	3.7
17	0.4	0.5	0.5	0.6	0.8	1.9	2.2	2.6	3.4
18	0.3	0.4	0.4	0.5	0.6	1.5	1.9	2.2	3.0
19	0.2	0.3	0.3	0.4	0.5	1.2	1.6	1.9	2.7
20	0.2	0.2	0.2	0.3	0.4	1.0	1.3	1.6	2.5
21	0.1	0.2	0.2	0.2	0.3	0.8	1.1	1.4	2.2
22	0.1	0.1	0.1	0.2	0.2	0.6	0.9	1.1	2.0
23	0.1	0.1	0.1	0.1	0.2	0.5	0.7	1.0	1.8
Total Percentage	100	100	100	100	100	100	100	100	100
Layer ID from outdoors to indoors (See Table 18)	F01	F01	F01	F01	F01	F01	F01	F01	F01
	M01	M01	M01	M01	M01	M01	M01	M01	M01
	F04	F04	F04	F04	F04	F04	F04	F04	F04
	I01	I01	G03	G03	I01	I01	I01	I01	M03
	G03	I01	I04	I04	G03	I01	M03	I01	I04
	F04	G03	G01	I04	I04	G03	F02	M03	G01
	G01	F04	F02	G01	G01	I04	0	F02	F02
	F02	G01	0	F02	F02	I04	0	0	0
	0	F02	0	0	0	G01	0	0	0
	0	0	0	0	0	F02	0	0	0

CTS

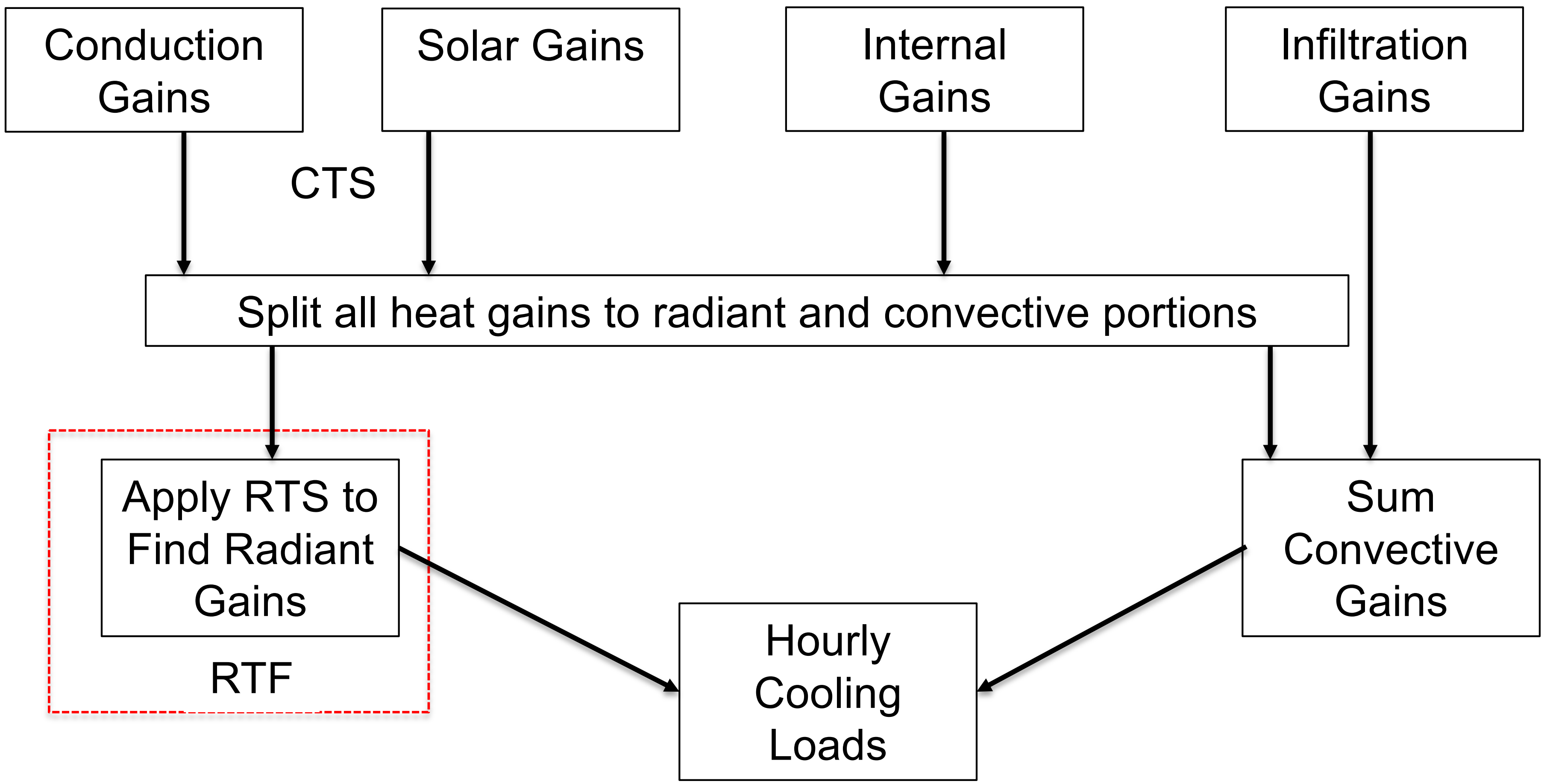
Table 18 Thermal Properties and Code Numbers of Layers Used in Wall and Roof Descriptions for Tables 16 and 17

Layer ID	Description	Thickness, in.	Conductivity, Btu·in/h·ft²·°F	Density, lb/ft³	Specific Heat, Btu/lb·°F	Resistance *R*, ft²·°F·h/Btu	Mass, lb/ft²	Thermal Capacity, Btu/ft²·°F	Notes
F01	Outdoor surface resistance	—	—	—	—	0.25	—	—	1
F02	Indoor vertical surface resistance	—	—	—	—	0.68	—	—	2
F03	Indoor horizontal surface resistance	—	—	—	—	0.92	—	—	3
F04	Wall air space resistance	—	—	—	—	0.87	—	—	4
F05	Ceiling air space resistance	—	—	—	—	1.00	—	—	5
F06	EIFS finish	0.375	5.00	116.0	0.20	0.08	3.63	0.73	6
F07	1 in. stucco	1.000	5.00	116.0	0.20	0.20	9.67	1.93	6
F08	Metal surface	0.030	314.00	489.0	0.12	0.00	1.22	0.15	7
F09	Opaque spandrel glass	0.250	6.90	158.0	0.21	0.04	3.29	0.69	8
F10	1 in. stone	1.000	22.00	160.0	0.19	0.05	13.33	2.53	9

COOLING LOAD CALCULATIONS DUE TO RADIANT HEAT TRANSFER

RTF

- Radiant Transfer Series Method (RTSM)



CTS = Conduction Transfer Series
RTF = Radiant Transfer Function

RTF

$$Q_\theta = r_0 q_\theta + r_1 q_{\theta-\delta} + r_2 q_{\theta-2\delta} + \ \ldots . + r_{23} q_{\theta-23\delta}$$

- ❑ Q_θ: Cooling load for the current hour θ
- ❑ q_θ: Heat gain for the current hour
- ❑ $q_{\theta-n\delta}$: Heat gain n hours ago
- ❑ $r_0, r_1, \ldots$: RTFs

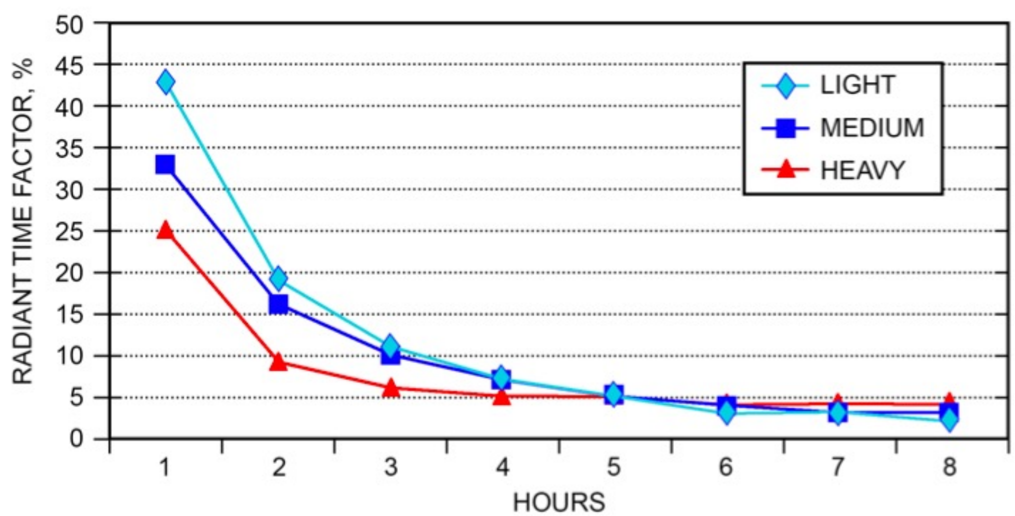
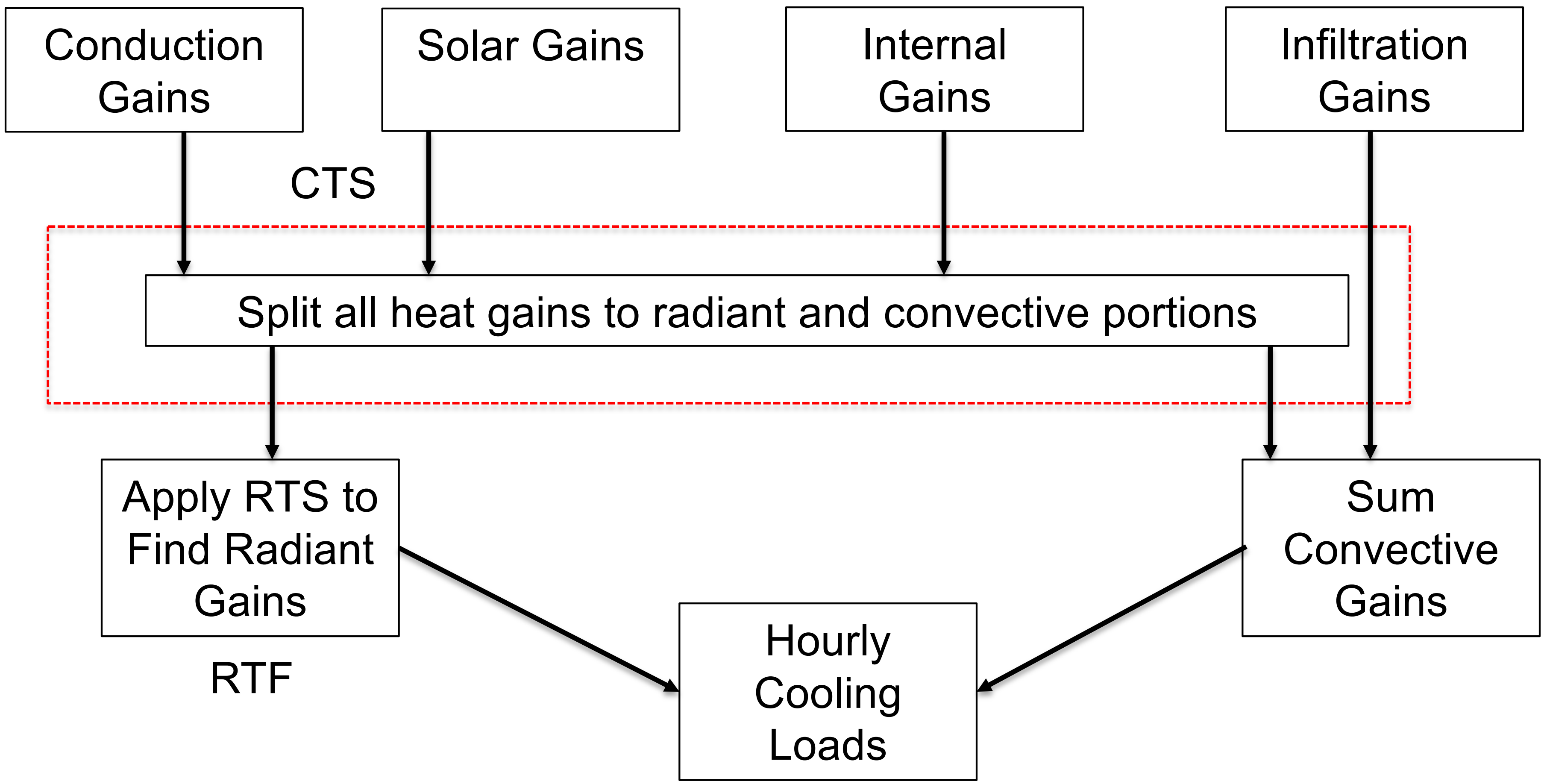


Fig. 11 RTS for Light to Heavy Construction

RTF

- Radiant Transfer Series Method (RTSM)



CTS = Conduction Transfer Series
RTF = Radiant Transfer Function

RTF

Table 14 Recommended Radiative/Convective Splits for Internal Heat Gains

Heat Gain Type	Recommended Radiative Fraction	Recommended Convective Fraction	Comments
Occupants, typical office conditions	0.60	0.40	See Table 1 for other conditions.
Equipment	0.1 to 0.8	0.9 to 0.2	See Tables 6 to 12 for details of equipment heat gain and recommended radiative/convective splits for motors, cooking appliances, laboratory equipment, medical equipment, office equipment, etc.
Office, with fan	0.10	0.90	
Without fan	0.30	0.70	
Lighting			Varies; see Table 3.
Conduction heat gain			
Through walls and floors	0.46	0.54	
Through roof	0.60	0.40	
Through windows	0.33 (SHGC > 0.5) 0.46 (SHGC < 0.5)	0.67 (SHGC > 0.5) 0.54 (SHGC < 0.5)	
Solar heat gain through fenestration			
Without interior shading	1.00	0.00	
With interior shading			Varies; see Tables 14A to 14G in Chapter 15.
Infiltration	0.00	1.00	

Source: Nigusse (2007).

RTF

Table 19 Representative Nonsolar RTS Values for Light to Heavy Construction

	Light						Medium						Heavy						Interior Zones					
																			Light		Medium		Heavy	
	With Carpet			No Carpet			With Carpet			No Carpet			With Carpet			No Carpet								
% Glass	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%	With Carpet	No Carpet	With Carpet	No Carpet	With Carpet	No Carpet
Hour	Radiant Time Factor, %																							
0	47	50	53	41	43	46	46	49	52	31	33	35	34	38	42	22	25	28	46	40	46	31	33	21
1	19	18	17	20	19	19	18	17	16	17	16	15	9	9	9	10	9	9	19	20	18	17	9	9
2	11	10	9	12	11	11	10	9	8	11	10	10	6	6	5	6	6	6	11	12	10	11	6	6
3	6	6	5	8	7	7	6	5	5	8	7	7	4	4	4	5	5	5	6	8	6	8	5	5
4	4	4	3	5	5	5	4	3	3	6	5	5	4	4	4	5	5	4	4	5	3	6	4	5
5	3	3	2	4	3	3	2	2	2	4	4	4	4	3	3	4	4	4	3	4	2	4	4	4
6	2	2	2	3	3	2	2	2	2	4	3	3	3	3	3	4	4	4	2	3	2	4	3	4
7	2	1	1	2	2	2	1	1	1	3	3	3	3	3	3	4	4	4	2	2	1	3	3	4
8	1	1	1	1	1	1	1	1	1	3	2	2	3	3	3	4	3	3	1	1	1	3	3	4
9	1	1	1	1	1	1	1	1	1	2	2	2	3	3	2	3	3	3	1	1	1	2	3	3
10	1	1	1	1	1	1	1	1	1	2	2	2	3	2	2	3	3	3	1	1	1	2	3	3
11	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	3	3	3	1	1	1	2	2	3
12	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	3	3	3	1	1	1	1	2	3
13	1	1	1	0	1	0	1	1	1	1	1	1	2	2	2	3	3	2	1	1	1	1	2	3
14	0	0	1	0	1	0	1	1	1	1	1	1	2	2	2	3	2	2	1	0	1	1	2	3
15	0	0	1	0	0	0	1	1	1	1	1	1	2	2	2	2	2	2	0	0	1	1	2	3
16	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2	2	2	2	0	0	1	1	2	3
17	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2	2	2	2	0	0	1	1	2	2
18	0	0	0	0	0	0	1	1	1	1	1	1	2	2	1	2	2	2	0	0	1	1	2	2
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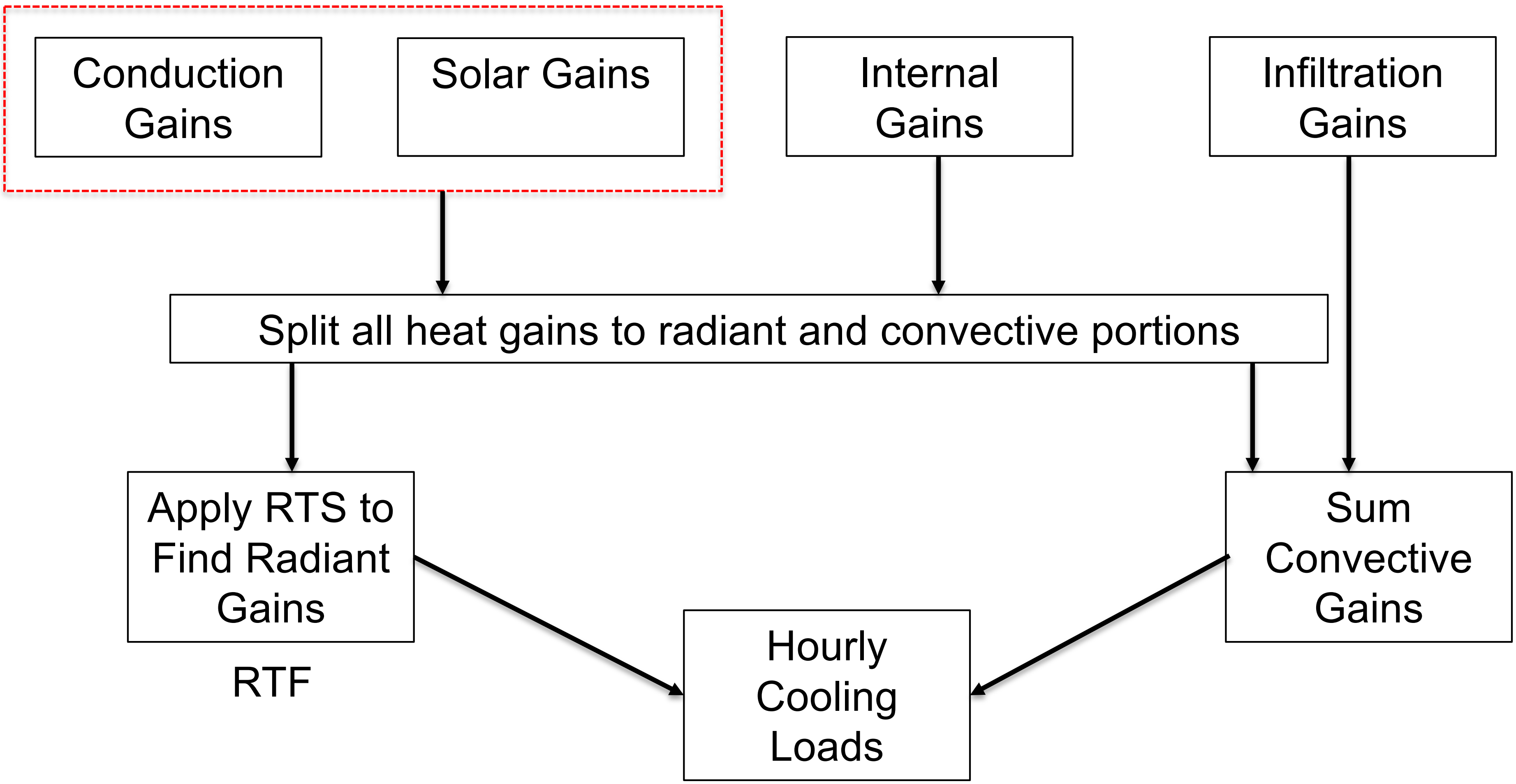
20	0	0	0	0	0	0	0	0	0	0	1	1	2	1	1	2	2	2	0	0	0	0	2	2
21	0	0	0	0	0	0	0	0	0	0	1	1	2	1	1	2	2	2	0	0	0	0	2	2
22	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	2	2	2	0	0	0	0	1	2
23	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	2	1	0	0	0	0	1	2
	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

COOLING LOAD CALCULATIONS DUE TO FENESTRATION (ONLY FOR INTERESTED STUDENTS)

Fenestration

- Radiant Transfer Series Method (RTSM)



CTS = Conduction Transfer Series
RTF = Radiant Transfer Function

Fenestration

- Contribution of fenestration glazing systems
  - Solar Heat Gain Coefficient (SHGC) is the fraction of incident solar radiation coming to the space through instantaneous transmission or absorption
  - Vary between 0 to 1
  - SGHC is needed to calculate heat gain

$$Q = UA_{pf}(t_{out} - t_{in}) + SGHC \times A_{pf}E_t$$

- Q: Instantaneous energy [Btu/hr]
- U: Overall coefficient of heat transfer (U-Factor) [Btu/h-ft^2-F]
- A_{pf}: Total projected area of fenestration [ft^2]
- E_t : Incident total irradiance [Btu/hr-ft^2]

Fenestration

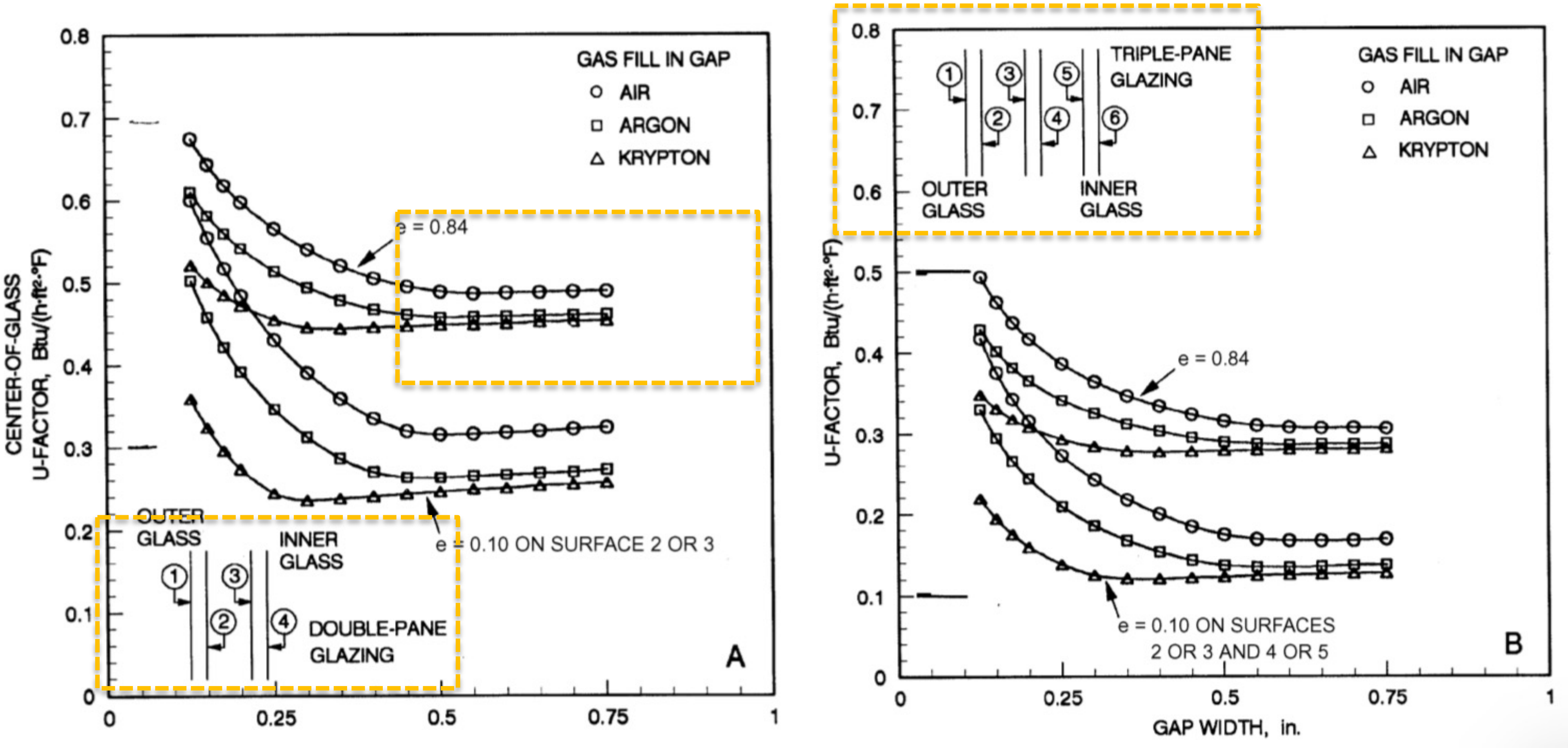
- For the fenestration assembly consider center of the glass (cg), edge of the glass (eg), and frame (f):

$$U = \frac{U_{cg}A_{cg} + U_{eg}A_{eg} + U_f A_f}{A_{pf}}$$

- U value for the center of the glass:

$$U_{single\ glazing,cg} = \frac{1}{\frac{1}{h_o} + \frac{1}{h_i} + \frac{L}{k}}$$

Fenestration



Fenestration

- Direct beam solar heat gain (q_b):

$$q_b = A \times E_{t,b} \times SHGC(\theta) IAC(\theta, \Omega)$$

- A: Area of the window (ft^2)
- $E_{t,b}$: Beam irradiance calculated using equations in Chapter 14
- $SHGC(\theta)$: Beam solar heat gain coefficient as a function of incident angle θ (values in Table 10 of Chapter 15)
- $IAC(\theta, \Omega)$: Indoor solar attenuation coefficient for diffuse solar heat gain coefficient (1.0 if there is no indoor shading device)

Fenestration

- Diffuse solar heat gain (q_d):

$$q_d = A \times (E_{t,d} + E_{t,r}) \times < SHGC >_D \times IAC_D$$

- A: Area of the window (ft^2)
- $E_{t,d}$: Sky diffuse irradiance using equations in Chapter 14
- $E_{t,r}$: Ground-reflected diffuse irradiance using equations in Chapter 14
- $< SHGC >_D$: Diffuse solar heat gain coefficient (Table 10 of Chapter 15)
- $IAC(\theta, \Omega)$: Indoor solar attenuation coefficient for diffuse solar heat gain coefficient (1.0 if there is no indoor shading device)

Fenestration

- Conductive solar heat gain (q_c):

$$q_c = UA(T_{out} - T_{in})$$

  - ❑ A: Area of the window (ft^2)
  - ❑ U: Overall U-factor including frame and mounting orientation (Table 4 of Chapter 15, Btu/h·ft^2·°F)
  - ❑ T_{out}: Outdoor temperature (°F)
  - ❑ T_{in}: Indoor temperature (°F)